

MODELING FOR CAMPAIGN ANALYSIS

LESSONS FOR THE NEXT GENERATION OF MODELS

DISTRIBUTION STATEMENT A

Approved for public release
Distribution Unlimited

EXECUTIVE SUMMARY

RICHARD J. HILLESTAD ♦ BART BENNETT ♦ LOUIS MOORE

The research reported here was sponsored by the United States Air Force under Contract F49642-96-C-0001. Further information may be obtained from the Strategic Planning Division, Directorate of Plans, Hq, USAF.

ISBN: 8330-2438-8

© Copyright 1996 RAND

All rights reserved. No part of this book may be reproduced in any form by any electronic or mechanical means (including photocopying, recording, or information storage and retrieval) without permission in writing from RAND.

RAND is a nonprofit institution that helps improve public policy through research and analysis. RAND's publications do not necessarily reflect the opinions or policies of its research sponsors.

Published 1996 by RAND

1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138

RAND URL: <http://www.rand.org/>

To order RAND documents or to obtain additional information,
contact Distribution Services: Telephone: (310) 451-7002;

Fax: (310) 451-6915; Internet: order@rand.org



MODELING FOR CAMPAIGN ANALYSIS

LESSONS FOR THE NEXT
GENERATION OF MODELS

EXECUTIVE SUMMARY

19961114 041

RICHARD J. HILLESTAD ♦ BART BENNETT ♦ LOUIS MOORE

Prepared for the
United States Air Force

RAND

Approved for public release; distribution unlimited

DTIC QUALITY INSPECTED 1

PREFACE

The purpose of this document is to complement the activities of the Air Force and others as they examine key joint campaign modeling issues, capabilities, and requirements for inclusion into new “next generation” campaign model development efforts. The issues outlined are believed to be of such importance that the successful development of a new model (or, for that matter, the enhancement or derivation of an existing model) may well hinge on the resolution of these challenges.

This document is a companion to the longer report entitled *Modeling for Campaign Analysis: Lessons for the Next Generation of Models*, MR-711-AF, which provides a detailed review of the issues discussed herein and discusses options for their resolution. That report is organized as a reference so that the reader interested in detailed discussions of particular issues, such as those associated with databases, model structure, and model development, can go directly to the relevant sections.

This research was conducted as part of our work in modeling and simulation improvement in Project AIR FORCE and was sponsored by the Director of Modeling, Simulation, and Analysis (XOM). The report should be of interest to the variety of modelers, analysts, and decisionmakers who use models as part of the campaign analysis process, especially those involved in defining requirements for new campaign models.

RELATED DOCUMENTATION

We have produced five reports and a research brief as part of this work. This executive summary provides an overview of important issues and approaches for campaign models designed for analysis. Still to come is the full report, which will address those issues in detail, describe alternative approaches, and discuss how a campaign model should be used in the analysis process. A third report, *The Theater-Level Campaign Model: A Research Prototype for a New Generation*, MR-388-AF, forthcoming, provides a more in-depth description of the important models we implemented in the Theater-Level Campaign model. The *MAPVIEW Users Guide*, MR-160-AF/A, 1993, describes a graphical user interface developed as part of the theater-level campaign work specifically for the generalized network gameboard that underlies the Theater-Level Campaign model. An earlier workshop report, *New Issues and Tools for Future Military Analysis: A Workshop Summary*, N-3403-DARPA/AF/A, 1992, describes conclusions reached at the start of this project about the need for new models for analysis in the post-Cold War era.

PROJECT AIR FORCE

Project AIR FORCE, a division of RAND, is the Air Force federally funded research and development center (FFRDC) for studies and analyses. It provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat readiness, and support of current and future aerospace forces. Research is being performed in three programs: Strategy and Doctrine, Force Modernization and Employment, and Resource Management and System Acquisition.

In 1996, Project AIR FORCE is celebrating 50 years of service to the United States Air Force. Project AIR FORCE began in March 1946 as Project RAND at Douglas Aircraft Company, under contract to the Army Air Forces. Two years later, the project became the foundation of a new, private nonprofit institution to improve public policy through research and analysis for the public welfare and security of the United States—what is known today as RAND.

CONTENTS

Preface	iii
Chapter 1	
INTRODUCTION	1
The Problem	1
Some Initial Distinctions: Campaign Analysis and the Campaign Model	3
Research Focus	5
Chapter 2	
APPLYING A CAMPAIGN MODEL TO ANALYSIS	7
Managing the Development Process	12
Overcoming Problems of Data and Integrating with Other Models	15
Creating Flexible Underlying Structures	17
Representing Decisionmaking and Command, Control, Communications, Computers, and Information	19
Achieving Transparency in the Use of a Campaign Model	22
Chapter 3	
CONCLUSIONS: A PROGRAM FOR THE FUTURE	25
References	27

INTRODUCTION

This report summarizes our experiences and observations in developing and applying models to support campaign analyses. Our goal is to provide key lessons learned to those involved in ongoing modeling efforts to move the technology of campaign modeling into the next generation. To this end, our primary purpose is to focus these efforts on improving analytic capability rather than on advancing computer science or on satisfying the ever-present demands for more and more detail in models. Our desire is to link the needs of analysis to the content and use of a campaign model, to describe some of the important new (and old) challenges for the next generation of models, and to discuss promising (and not so promising) approaches.

THE PROBLEM

The U.S. military's force structure and defense strategy are increasingly affected by the use of computer models. New technologies promise to facilitate even broader use of models in the Department of Defense through advanced graphics, networked simulations, and much faster computation. For example, simulations netted with real exercises fighting against *virtual* and live forces in widely distributed geographic locations have already been demonstrated.¹ The promise

¹Such demonstrations include the Synthetic Theater of War-Europe (STOW-E) as part of the Atlantic Resolve (formerly Reforger) exercise, the Ballistic Missile Defense Organization (BMDO) Technical Engineering Demonstration (TED), DARPA's Warbreaker, and the Army's Anti-Armor Advanced Technical Demonstrations

of lower exercise costs, of reducing (or perhaps eliminating) some high-cost components of weapon tests, and of using more realistic models for analysis continues to drive large investments in modeling and simulation technology and software.²

Despite these investments and the impressive technological demonstrations, many aspects of the current state of defense modeling are disturbing. The models in use, largely developed for NATO–Warsaw Pact Campaign Assessment calculations during the Cold War, do not reflect some fundamental changes in the nature of warfare; the effects of modern systems, particularly sensors; and command and control. Individual military services are concerned that the models do not adequately and fairly represent the contributions of those services in a joint warfare arena. Many believe that the national security environment has changed so dramatically in terms of uncertainty about threats, declining defense outlays, and the needs for analysis that the fundamental nature of the models in use for defense analysis must change. Political and military leaders are confused by the proliferation of models and model-based study results, which often provide conflicting conclusions and diverse information. Furthermore, decisionmakers frequently desire rapid responsiveness that current-generation campaign models and their users often cannot deliver.³

In a February 1995 memo to the Director, Program Analysis and Evaluation, then–Deputy Secretary of Defense John Deutch said,

Joint theater models play an important role in assessing the capabilities of our forces and programs to execute our strategy and in measuring the impact of changes in the defense program on warfighting capabilities. As we discussed at the recent review of the mobility

(A2ATD). (U.S. Department of the Army, 1994; M1A2 SIMNET-D Synthetic Environment Experiment Committee, 1993; Johnson, 1994.)

²For a description of the distributed simulation plans see DIS Steering Committee (1994). It is estimated that DARPA spends \$130 million annually on Advanced Distributed Simulation activities, including Warbreaker and STOW. The Army is estimated to spend \$300 million in DIS-related areas.

³It should be noted here that responsiveness and the ability to analyze a complex, campaign-level issue in some breadth and depth, rather than the ability to run a model rapidly, are really the sources of tension. A very real tradeoff exists, sometimes not appreciated by decisionmakers, between the need for responsiveness and the quality of the answer.

requirements update study, many of our analytical efforts have highlighted the limitations of the modeling tools currently available. Those models are grounded in Cold War theory about the use and deployment of forces and the nature of combat operations. They have only limited capability to address key issues from an integrated joint operational perspective. They are also unable to measure adequately the value of the Department's investments in reconnaissance, surveillance, and intelligence and new weapon systems. Nor do they adequately represent the impact of such factors as readiness and training, logistics, or weapons of mass destruction. Moreover, the realism of the basic methodologies that drive the models' results is in need of review. Therefore, as a matter of immediate concern, it is essential to upgrade and refine our current models and to begin development of a new generation of models that the Department will need to address critical joint warfare issues effectively in the future.⁴

The current reliance on quantitative analysis and models has increased, while the downward pressure on defense budgets has put funding of modeling, simulation, and analysis activities in question. As decisionmakers grapple with this problem, there is a trend to try to consolidate and improve the models once and for all, as though it is possible to get them "right" and thus remedy the situation.

SOME INITIAL DISTINCTIONS: CAMPAIGN ANALYSIS AND THE CAMPAIGN MODEL

The focus of this discussion is on campaign analysis, although much of what we have to say applies more generally.⁵ The importance of campaign analysis for defense problems is that it embraces the big picture in terms of the total forces involved, including the joint actions of air, ground, and naval forces, as well as the play of coalition forces. Campaign analysis considers many of the most impor-

⁴As a result of this memo to PA&E, a four-phased initiative was begun. Phase one specifically deals with the near-term enhancement of an existing model (TACWAR). Phases two and three focus on future models and modeling environments for the midterm (based on a joint model development) and long-term (based on the high-level architecture). Phase four cuts across all these activities to provide field support of the models.

⁵For convenience, we often drop the "campaign" modifier and use only the term "analysis."

tant determinants of the outcome of a war, such as territory lost, achievement of air superiority, and overall attrition. At the campaign level one can start to gain insight into “how much is enough” military force, because all forces are included.

Campaign analysis is also used to study the interactions of strategy, force allocation, and system capabilities. For example, the addition of a more-effective surface-to-air capability may permit an allocation of more combat aircraft to attack enemy ground forces rather than using them for defense. Typically, these models have represented territorial conquests or destruction of enemy targets but could also include naval exchanges and blockades or some aspects of information warfare. Cumulative effects over time are important in campaign analysis, and multiday strategies, objectives, and outcomes must be considered. Finally, it is in campaign analysis that many important scenario factors play, such as timing of the deployment of forces, availability of ports and air bases, nearness of the battle to ocean access, and the strategy and operations of the enemy.

Models for defense analysis range from engineering models of specific subsystems (a model of an aircraft radar system, for example) to engagement models (a surface-to-air system engaging aircraft) to mission models (a model of a complete flight of aircraft from takeoff to attack on a target and back again) to the campaign model, which represents a set of missions, operations, or battles in a military campaign.⁶ Campaign models are also sometimes referred to as “theater” models because their focus and scope are usually associated with a full theater of conflict even though there might be more than one campaign associated with a theater.

Another distinction in combat models is between the tactical, operational, and strategic levels of conflict. We will use the term “campaign model” to encompass the operational level of conflict, fully understanding that this represents a somewhat different scope in concepts and analysis from the campaign or theater level. Many of the points we discuss equally apply across the broad range of modeling and analysis.

⁶Some campaign models allow simultaneous analysis of multiple theater conflicts. RAND’s Joint Integrated Contingency Model (JICM) has such a capability, as described in Bruce Bennett et al., 1994.

RESEARCH FOCUS

This research concentrates on what we believe to be some of the most important problems and issues in campaign-level modeling and analysis. Although our focus is on campaign-level modeling as it is developed and applied to analysis, many of these issues are applicable to other types of models and for model uses other than analysis. We believe that overcoming the difficulties raised here is essential to future progress in model-based defense analysis, and attempting to develop new models without their resolution will lead to only marginally better ways of doing things we already know how to do. Furthermore, it is most important that these issues be addressed very early in the development of the model—during the conceptual design stage.

This report does not offer a comprehensive solution to the problems of campaign analysis and modeling. Instead, it sets out the six hardest things we confronted in building and applying our own campaign model.⁷ We have considered the relatively modest progress made in campaign modeling, relative to the nearly half-century of effort devoted to it, and determined that this is due in part to the lack of accessible documentation not only on the models themselves but on the lessons learned from both successful and failed analysis and modeling efforts. We hope to share with the community the lessons we have learned so that our successes can be exploited instead of relearned and so that our failures can be avoided instead of recommitted.

We have selected this list because we believe that these are clear areas for which positive steps can be taken, and because we have something specific to contribute. We selected six as a small number

⁷As part of research on military campaigns of the future by RAND's Project AIR FORCE and Arroyo Center, we have designed and coded the prototype Theater Level Campaign (TLC) model for the investigation of joint force issues in the post-Cold War era (see Hillestad and Moore, forthcoming). For this model we investigated advanced features for representing maneuver in "nonlinear" battlefields; structures for better simulation of command, control, and information systems; advanced setup and graphic user interfaces; and recent state-of-the-art, object-oriented simulation software (CACI Products Company, 1994). While this document is not specifically about TLC or any other model, it does draw from our experience in many of the most difficult or controversial aspects of modeling to support campaign analysis.

of issues that can be concentrated on that still covers a range of the thorniest issues that must be resolved.⁸ These are:

1. applying a campaign model to analysis
2. managing the development process⁹
3. overcoming problems of data and integrating with other models
4. creating flexible underlying structures
5. representing decisionmaking and command, control, communications, computers, and intelligence (C⁴I)
6. achieving transparency in the use of a campaign model.

Chapter Two of this report describes these six areas in more detail. Chapter Three proposes a plan for the future for resolving some of these difficulties.

⁸Our list of the six hardest things is unlikely to match the reader's exactly. Furthermore, our perspectives on these issues may well differ. We encourage readers to document their own lists of "hardest things," for which they will have superior experience and ideas, and contribute the results to the overall benefit of the community.

⁹This could be either for a new effort or for enhancements to an existing model.

APPLYING A CAMPAIGN MODEL TO ANALYSIS

Using a campaign model for analysis requires maintaining the proper relationship between the model and the analysis. **What seems to have been lost in many of the modeling developments is that analysis is a “process” and that the model is but one tool in that process.** A single computer run of a combat model serves almost no purpose at all, because it is merely a hypothesis about how things might come out and provides at best a very weak prediction of what might happen. Far too often, unanalyzed model results are transcribed onto transparencies. The model is only one of many components of the analytic process, which includes

- formulating the problem
- specifying objectives, constraints, and measures
- obtaining and manipulating data
- generating, evaluating, and prioritizing alternatives
- developing and testing hypotheses.

When analysis is performed well, for example, unknowns and uncertainties are managed, and recommendations are developed that account for these complexities and their related risks. Analysis and modeling, particularly modeling enhancements, focus on big-picture issues, such as defense strategy in a multipolar world and the implications of new problems and phenomena in that world.

Generally, the analytic process iterates among the above steps. The problem may be reformulated after looking at the alternatives or syn-

thesizing the initial results. Interactions with the decisionmakers may lead to changes in the objectives, the measures, the set of possible alternatives, the models, and expectations about the future. The role of the model in this framework is not to dominate or supplant these other steps, but to provide the means for quantifying the effects of systems, tactics, and strategies on measures, given the scenario. Thus, it glues the different components together into an integrated framework. An analysis, particularly of military operations, should involve many computer runs, tests of hypotheses, sensitivity tests, "a fortiori" arguments,¹ identification of cause and effect, and in general an elucidation of the conditions under which a hypothesis holds true and why. In fact, a good analysis can overcome many of the shortcomings in the representational aspects of a model. This is one of our major themes—that analysis, particularly in addressing military operations, should drive model requirements. The problem is not so much with the models as it is with the lack of recognition of what constitutes good model-based analysis and the conditions under which such quantitative analysis is appropriate. Thus, we provide the following guiding principles:

The analyst plays the central role. The analyst is central to the process because he or she discerns what the analysis process implies or does not imply about the problem, determines the set of experiments, performs the tests (involving model runs), identifies the cause-and-effect relationships, adjusts the model or hypotheses, overcomes the limitations of the model, integrates results, and provides the explanatory and educational tutorial about the results. No model that we know of provides these functions, and they require much more than the mechanical ability to develop inputs and display outputs. A key part of this is preparing analysts to perform campaign analysis and employ, where appropriate, a model. It is essential to know when the analyst is adequately prepared.

The analysis leads, not the model. It is surprising how often this principle seems to be violated. The principle is that one should first consider what has to be done from an analytic viewpoint (what is the

¹ Such arguments are done by making favorable assumptions about a policy option. If, under these assumptions, the option does not pay off, it is unlikely to work well under less-favorable assumptions. Frequently, these favorable assumptions are easier to model than more realistic ones.

problem? what are the objectives? what are the measures? how should the measures be calculated?) and then choose the appropriate measurement tools or models within that context. Too often problems are approached the other way (what can we use our favorite model to calculate?). Too often an analytic question is changed to adapt to a model rather than the other way around.²

The drive for detail is not always warranted in models for analysis.

Over the years, various scientists and authors have also suggested the principle we advocate here. For example, Einstein once stated that a model should be as “simple as possible but no simpler.” This is also implied in the principle of *Occam’s Razor*³ and the more pedestrian variant called KISS (Keep It Simple, Stupid). This principle recognizes the importance of the ability to explain results and that unnecessary detail in a model will hinder the ability to identify cause and effect. These are often in direct contradiction to the inclination of some in the community for verisimilitude in models. For example, Newton’s laws, which leave out the effects of speed on mass, are perfectly adequate for the analysis of most land and air vehicles. A simple model that lists when resources become available in the theater (rather than a complete strategic mobility model) may adequately represent the deployment of different units when more precisely calculated arrival times are overwhelmed by uncertainties or are not a critical factor in the analysis. And unnecessary attempts to achieve realism can easily impede an analysis. If a complete strategic mobility model is used when it is not necessary, the setup time and data requirements would unnecessarily increase the cost and time of the analysis without really making it better. Conceivably, the cost in time could reduce the number of trials and cases, resulting in less-complete analysis.

² Given this principle, an important issue is how to deal with the difference between the relatively short time in which an analysis must be done and the relatively long time required to develop a specifically tailored model. The answer seems to be either a single multipurpose model that can deal with the very broad issues or a set of models (perhaps within a single modeling environment) capable of analysis in more narrowly defined policy areas.

³ *Non sunt multiplicanda entia praeter necessitatem* [multiplicity ought not to be posited without necessity]—the principle of Occam’s Razor.

So what does this mean for a campaign model? First, we need to develop a better understanding of warfare, particularly future warfare, and methods for representing critical interactions. Second, since the level of detail cannot be completely predetermined, some flexibility in representation (multiple resolution) must be a fundamental part of the model architecture, along with the ability to take out completely the portions that are irrelevant to the analysis at hand. Flexibility must often be traded off against simplicity in the same way that the breadth of analytic requirements must be traded off against model development constraints.

Training and analysis models will differ from each other. Although there may be some commonality among components, training and analysis models are likely to diverge in what they are trying to accomplish and hence how and what they represent.⁴ Training models must present a reasonable set of stimuli and responses for the trainee, or the wrong lessons may be learned. Thus, verisimilitude for specific training objectives may be a desirable feature. As we have just noted, this verisimilitude can get in the way of analysis.

Models of combat at the campaign level cannot predict outcomes in the strict sense of other scientific experimentation. There are too many uncertainties in terms of human interactions, unknown initial conditions, unknown combat phenomenology, and unknown effects that prevent strict prediction with a campaign model. In the end, the model, as a set of hypotheses about campaign warfare, can only be judged to be plausible and to be consistent with our best views of the world for a given set of initial conditions and assumptions.⁵ With these assumptions clearly described, the model can be used to help identify and analyze the relative importance of various systems, operational concepts, and force structures.⁶

⁴For a much more detailed discussion of the differences between training and analyses and the associated models, see Dewar et al. (1996).

⁵A view of the world may be a very informal mental model, historical experience, expert opinion, or a more-formal set of models and data. We realize that there will *always* be conflicting views of the future world. What we argue for here is a rational consideration of plausible variations and consistent treatment of issues across these variations.

⁶Even if a model is not strongly predictive, it can be successfully used for a number of significant purposes. See Dewar et al. (1996) and Hodges and Dewar (1992).

Models, no matter how realistic, will not replace analysis. Too often in the current environment, an analysis is simply equated with one or more runs of a combat model. If this were really true, the approach of adding detail to models and removing analysts from the loop might be correct. Such “analyst-free” models have actually been suggested. Based on our previous description of analysis, this is dangerously wrong. There is much more to analysis than a set of computer runs.

The analytic process should depend on multiple independent models and multiple independent analyses of the same problem. The current emphasis within DoD may be interpreted as an attempt to consolidate the number of models with a goal of one last and final supermodel for campaign analysis. If combat were devoid of unknowns or uncertainties, or at least were replicable, this engineer-type approach might well be preferred. However, we believe it to be unsuitable for campaign analysis, where the goal is more to learn and explain than to predict. Comparative analysis often highlights assumptions about data, scenarios, and effectiveness that are not apparent even in multiple trials with a single model. Instead of reducing the models to a single representation, a preferred approach may be developing methods for linking diverse analyses to a common point of reference. This will continue to allow creativity and innovation at the same time as it allows decisionmakers to be able to better understand the context of a given analysis and integrate across the results and recommendations. To the extent that DoD efforts encourage the capability to include multiple models (perhaps integrated within an architecture), we endorse this approach.⁷

Education is an important element of analysis. Analysis and the use of models should educate, not merely “sell,” the analyst and the decisionmaker. If the “education” doesn’t occur, we have probably

⁷ We are, however, concerned that this may simply be yet another way of building a supermodel that will be “all things to all people.” Along the continuum of modeling architectures, from a single large model to the flexible plug-and-play environment, are a variety of approaches that have been experimented with in the past, each with its corresponding capabilities and limitations. The community has had a full range of experiences with single large models (such as TACWAR and Thunder at one end of the spectrum), whereas the extreme of fully flexible architecture is far less tested or proven.

failed as analysts. The education process needs to be included in the analytic plan.

The use of models may not enhance creativity in the analytic process.

This is the negative side of the use of models in analysis. Because models provide a limited view of the real world and represent only one set of hypotheses about the relationship of things, they do not lend themselves to the development of new hypotheses or the examination of effects outside their scope. Campaign models developed during the Cold War to simulate conflict between NATO and the Warsaw Pact did not generally represent the maneuver of ground forces, instead focusing on attrition warfare as the “accepted” manner for analyzing the war. This constraint caused analyses of the conventional balance to emphasize weapon system kill potential rather than mobility, flexibility, and information systems. To overcome such limitations, people must be involved. Model limitations may be overcome through the use of games (model supported or not), brainstorming, or other methods, but it is generally foolish to expect a model itself to provide much in the way of creative insights about a problem or its solution.

MANAGING THE DEVELOPMENT PROCESS

The development of a new campaign model or the making of significant improvements to an existing model is not a light undertaking. Managing the process includes not only configuration management of the code, but also (1) documenting the overall rationale for the model, (2) establishing requirements and methods for calculating measures and representing objects, (3) using resources successfully (people, time, and money), and (4) dealing with organizational constraints. Generally, there is much more to the development than expected; because much about the combat phenomenology is not understood well enough to codify, there is considerable risk and uncertainty that the final outcome will only be a technical, not a substantive, improvement over what already exists. Too often, unreal expectations and an unconditional “can do” attitude can lead to development plans and decisions not seasoned with the wisdom and caution of experience. This can spell disaster on the model-development trail.

There are many reasons to develop new models, not all of which have to do with analytic needs. Motivating factors range from the desire to take advantage of new computer hardware and software to the creative fun of developing something new. Perhaps the most important reason is to better represent phenomenology hitherto omitted in models and to create better methods for exploring uncertainties and unknowns. There are also strong disincentives in the form of cost, training requirements, organizational inertia, and sustainability. Too often, however, promises based on unwritten software and considerable underestimates of the costs and development time required lead to the premature initiation of a new model development.⁸ *Although we heartily endorse an ongoing process of modeling as a means of improving understanding and codifying what we learn about combat, the decision to develop a new campaign model for analysis should be approached with considerable logic and planning and should be as independent as possible of the organizational competition of the various DoD analysis agencies, services, consultants, and contractors.*

A series of questions about the rationale for a new model should be asked. These include

1. What is the range of analytic needs for the model?
2. Will the new model simulate phenomenology not represented in existing models?
3. Can we do a significantly better job at representing those phenomena already included in existing models?
4. How does the development schedule compare to the historical experience in developing such campaign models?
5. How precisely are the design requirements defined?
6. Who is on the development team, and what is the members' experience in producing this type of model?
7. What are the near-term expectations of decisionmakers?

⁸We note that many new modeling developments are associated with an overall architecture or environment to facilitate the coding, use, and maintenance of the model or models. Our recommendations apply to these development efforts as well.

8. Has there been a study of the existing models to determine if they can meet the need or if they can be more easily modified to accomplish the goals than trying to build a new model?
9. Does the new model have the support of the various organizations that are expected to use it?
10. What constraints on cost, people, and time resources will apply to the use of the model?

Given satisfactory answers and a decision to develop a model, many aspects of the design and development of a new model need to be understood, including the establishment of functional requirements, defining the underlying structure of a campaign model, creating realistic expectations, prototyping, testing, object-system modeling, choosing the level or levels of aggregation, defining the operating environment, determining the data requirements, and phasing in the new model.

One key decision to be made in the development process is how submodels will be linked to the simulation. A variety of approaches can be imagined—creating one big model, confederating the models with a model-specific interface, linking the models with a generalized set of communication protocols, designing an overall architecture or environment in which models can be “plugged-and-played,” and establishing a loose-knit hierarchy or family of models. Each of these methods has advantages and disadvantages in terms of maintaining the appropriate conceptual linkage between the models, achieving model flexibility, and demonstrating operational feasibility. The purpose of the model and how the simulation development is managed will determine in large measure which approach should be used.

Ten of the most important pitfalls that can be avoided with appropriate planning are

1. not involving the modelers and/or the prospective analysts in the entire design process
2. premature attempts at analysis with a new model

3. not performing early tests of both model components and the full model with realistic problems⁹
4. unrealistic schedules and attempts to satisfy an unrealistically diverse range of requirements
5. not knowing what is hard, what is easy, and what we do not know how to do
6. not establishing organizational and institutional issues and influences on the development
7. not considering sources of data early in the development
8. defining requirements independent of the analytical framework and resource constraints
9. not spending enough time learning what has been done in previous models
10. believing too strongly that new software, modeling, or data paradigms will make all the hard problems easier.

OVERCOMING PROBLEMS OF DATA AND INTEGRATING WITH OTHER MODELS

The data are often more important than the model. Because of the quantity and breadth of data required, it takes a great deal of care not to have errors in the input data of a campaign model. There are other reasons that data tend to dominate modeling in performing analysis. Data preparation is often the most time-consuming and resource-intensive aspect of the analysis. Given the time urgency of many analyses, there are many opportunities to make errors, and resource limitations cause pressure to take shortcuts by using old or inappropriate data sets. Data become even more important in the current trend to define more and more of the object representations, processes, and logic of a model as data. The distinction between model code and data is increasingly blurred with modern computing languages.

⁹ Items 2 and 3 directly oppose each other. Pushing the model into production too soon can be very disruptive. However, not demonstrating capabilities early can be fatal.

Database structures and processes interact with the model. Once the databases and input structures and processes are created, changes to the model, such as objects in the model, will likely require different data or different aggregations of the data. This will require changes to the database structure, including new or modified input files, database processes, and new input processes within the model itself. It may also call for changes in the graphical user interfaces and any preprocessors for the input files. Thus, model changes can ripple through all of the input-associated processes and the organization of the input databases. The unfortunate result is that these aspects of the input processing create very real constraints on how the model can be changed and inhibit the flexibility of the model. An important element of the design of a flexible model is to create a set of flexible input tools and model, data, and coding structures.

Data input and output processes can greatly enhance a model and its usability. The data handling in modern campaign models can be assisted greatly by various input and output processes and standards. Graphical user interface methods to limit-check and cross-check data, data dictionaries, database manipulation functions (such as aggregations), and data output processes (such as visualizations) all reduce the work of data preparation and assist in the important checking and verification of the data.

Much of the data must be developed from detailed (higher-resolution) models. Because of the lack of any other data source (history, training, tests, or even expert opinion), the sources of many data items for a campaign model are the computations of other, higher-resolution models. Historical data, for example, are typically not for the right situations, not well documented, or of such an aggregate nature that they can only be used as a benchmark for the data the analysis requires. This is not to say that data from more-detailed models are unconditionally better than these other sources, but rather that their use is an alternative means that is often turned to as the preferred approach. The process of “tuning” to a higher-resolution model is an art and requires a knowledgeable analyst to determine how to aggregate the data, when the approximation is good enough, what cases to use from the high-resolution model, and which parameters to adjust to achieve a good approximation. Aggregation can be done against time, geographic dispersion, types of objects, or measures. The approach, data, and tests of the

approximations should be published and subject to peer review to help establish credibility and consistency. Unfortunately, very few of these approaches have been openly described or performed in this manner.

Consolidate data-production efforts. Our final point about data is that a common effort by the defense community could reap dramatic benefits. Such an effort would involve sharing data, critiquing approaches for data generation, and testing different approaches to linking models and aggregating data. In the current environment, there is too much redundant effort at developing databases and too little testing and review of approaches, including selection of sources, embedded assumptions, and appropriate usages. Both the quality and timeliness of analysis suffer from the current organizational barriers that unnecessarily impede data access and lack of scientific approaches to data production across the wide variety of potential sources.

CREATING FLEXIBLE UNDERLYING STRUCTURES

By the underlying structures of a campaign model, we mean the treatment of simulated time and events, the interfaces with the analysts, the representation of spatial objects, the approach to representing command and control, the simulation of inherently random or uncertain events, and the type of software construction used. The choice of structure, one of the most important decisions with respect to any model development, determines how objects and information can be aggregated and what the basic level of resolution or potential for multiple resolution the simulation can represent. The structure affects the adaptability of the simulation to a range of analytic problems, the efficiency in processing, the transparency of cause-and-effect relationships, and the ease with which future changes can be made. These structural choices must be made early in the design phase of a model and subsequently affect all other aspects of model development. They must be resolved in the context of the analytic requirements and development constraints.

To understand the effects of structural choices, one need look no further than many of the current campaign models. The Cold War spawned a set of ground-warfare campaign models that represent ground operations as a set of "pistonlike" movements. Many of these

models are still in use and perhaps appropriate for some applications, but constrain the ability to simulate maneuver warfare so vital to representing combat in some regions of the world. In a similar vein, many of the early representations of theater air operations used “time-stepped” models of air and ground operations with relatively large time steps—a few hours to a day. While perhaps adequate for large-scale, doctrinal air operations, these models limit the ability to look at timing and command and control issues associated with both friendly and threat systems employing new capabilities (such as onboard and off-board sensor systems) and new concepts (such as reactive maneuver).

It is not so much that specific structural choices are inherently bad but that their limitations should be explicitly identified and understood when the choice is made. Furthermore, some structures are less limiting than others in terms of campaign-level representation. For example, flexible network structures can represent both piston movement and nonlinear maneuvers. Decision tables and goal-seeking algorithms can be used in place of scripts, but not vice versa. The tradeoff between flexibility and the cost to develop, use, and maintain a particular structure must be wisely considered.¹⁰

The components of structure of a campaign simulation that we address in detail in the main report include

1. simulation time management—whether time is advanced in event steps, fixed time steps, or continuously
2. spatial structure—the representation of movement, object positions, and terrain
3. stochastic structure—random or deterministic
4. software structure—the software paradigm, such as object-oriented coding, structured programming, and process-oriented programming
5. distribution structure—distributed processes, distributed trials, single processor, and parallel processing

¹⁰Cost is used very broadly here to include monetary cost, time, and skill levels that must be expended. Flexibility and cost are typically directly opposed to each other. More is said about specific options in the main report.

6. human interaction and command and control structure—closed, open, scripted, human-in-the-loop, semiautomated planning, and decision table
7. resolution structure—fixed, variable, and selectable resolution.

REPRESENTING DECISIONMAKING AND COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, AND INFORMATION (C⁴I)

Decisionmaking and C⁴I issues dominate much of campaign analysis. At the campaign level, the problem to be addressed is often not how much force there is, but how it is used. Despite the importance of this problem, it remains the least understood and most inadequately modeled part of most campaign-level simulations. In some models, nearly perfect battlefield intelligence is simulated, and each side has unrealistically perfect knowledge of the other side's positions, forces, capabilities, and intents. Furthermore, nearly instantaneous planning and execution are implicitly represented by many of the models and in effect assume a nearly perfect command and control process. Many combat phenomena are less than adequately treated in the current generation of combat models. We believe C⁴I is the one phenomenon most urgently in need of improvement.

It is believed by many that the U.S. dominance of the information assets in a campaign should provide a distinct advantage over most of our potential opponents. The ability to view opposing forces and maneuvers, to disrupt planning and execution, and to feed misinformation while, at the same, time denying the enemy the same capabilities against us should alter the character of the war and provide U.S. and friendly forces with a distinct advantage. Campaign models should show these interactions and help analysts determine the value of acquiring various C⁴I assets.

The starting point for understanding C⁴I in a campaign model is to look at the decisions and force allocations that depend on the effectiveness of C⁴I. At the highest level, there are campaign objectives and the commander-in-chief's strategies for achieving these objectives within the constraints of the campaign. These include the phasing of the campaign and the emphasis on broad operational objectives: targets destroyed, air superiority, and territory won or

lost. At the next tier, the operational level, are the decisions about force allocations, priorities, and timing needed to achieve operational objectives. These include how multirole aircraft are allocated to missions over time, how the ground forces are reinforced, and what types of targets to emphasize over time. We group the decisions at the third level as tactical taskings. These include the allocation of weapon fires of a ground unit against the weapons and forces of the other side, the allocation of fighters against penetrating bombers and escorts, the choices about which airfields or strategic targets to attack, and the allocation of surface-to-air fire of a coordinated (netted) set of surface-to-air missile fire units.

In general, it is difficult at the campaign level to provide a detailed representation of all of the information-gathering objects, the communications, and all levels of command and control. The problem, then, is to show the essence of C⁴I in a campaign and to determine how to model and analyze its effects. We next examine some approaches to capturing these effects more fully.

Many models use scripted force allocations as inputs to the simulation. These scripts do not adapt to changes in situation during the course of the simulated battle. Most models do not adequately reflect the competitive nature of decisionmaking between opponents on a battlefield. Thus, a great deal of manual intervention, planning, and replanning of force allocations is required. We desire to find alternative means that automate some of these processes. In some cases, we may wish to simulate the behavior of human decisionmakers. However, in many analyses, it is important to have the best possible decisions made, according to doctrine or based on some simple rules of thumb that might include cultural biases. The method depends on the application. Thus, what we are arguing for is the ability to represent the decisionmaking process in a variety of different ways and to be able to select the method that best suits the analytic need.

We compare some of the approaches RAND and others have tried and describe some of the aspects of command and control phenomenology that are not yet well enough understood to include in a campaign model. The approaches include:

- **Interactive or human-in-the-loop.** These simulations allow for human beings to interact with the flow of the simulation—not just at the beginning of the run but throughout.
- **Scripted decisions.** This method does not rely on human interaction throughout the simulation. What happens and when are specified up front with consistency and repeatability. An alternative technique to obtaining a script is to execute the model iteratively. At each decision point, the option is chosen that is viewed as best in light of what has been learned from previous runs of the model.
- **Rule-based or expert systems.** To introduce adaptability into scripts and mimic doctrinal guidance, one may instead adopt a set of rules. The rules are sometimes organized into decision tables. Decision tables list the conditions and, for each condition, the corresponding decision to be taken.
- **Tactical algorithms.** Several lower-level, yet still important, decisionmaking processes may be implemented directly in code. These tend to be more-complex extensions of rule-based systems.
- **Value-driven method.** The outcome state of each possible decision is estimated or predicted, perhaps with a “look-ahead” method. The outcome state is evaluated according to some metric, and the action that incrementally optimizes this function is selected.
- **Learning algorithms.** This extension of value-driven methods allows the simulated decisionmaking process to *learn*. A numeric “fingerprint” of the current state of the system is retained whenever it makes a decision. Future decisions, although unlikely to be based on exactly the same circumstances, examine previous fingerprints and the desirability of the outcome. When circumstances exist beyond the reasonable bounds of previous decisions, other methods are used to determine the actions.
- **Objective-driven optimization and gaming methods.** Optimization techniques are used to search the decision space efficiently. The function that determines the value of the decision is called the objective function, and the principles of mathematical programming are brought to bear to maximize (or

minimize) an objective function efficiently. Some of the methods employed involve linear programming, shortest path, maximum flow algorithms, or other search techniques (such as genetic algorithms).

These various approaches to the decisionmaking process have capabilities and limitations related to their ease of implementation, ease of use, ability to be adaptive, ability to represent specific decisionmaking processes better, and inclusion of natural biases.

ACHIEVING TRANSPARENCY IN THE USE OF A CAMPAIGN MODEL

One of the key challenges of modeling for analysis, especially with large campaign models, is to understand clearly the cause-and-effect relationships that occur within the model. Outcomes may result from new systems, strategies, assumptions, effectiveness inputs, or even errors in the model or data. Rather than just stating model results, the analyst carries the responsibility of identifying how changes in the inputs affect output measures and how these are in turn affected by other data or assumptions. Because a campaign model has a formidable quantity of data representing the forces, effectiveness, scenario, and setting, it is not generally feasible to vary all combinations of the input data.

Most analysts realize that it is not enough to present a set of outcomes from a campaign model. Furthermore, the analyst should be able to motivate and argue model results without reference to the model. Along with the outcomes, one must describe the assumptions, describe the data used, and—most importantly—provide the logic to explain why the results are as they are. The ability to explain the results depends on transparency. This in turn depends on both the analytic process and the analyst's understanding of the relationships in the campaign model—explanation of the results is only partially a function of the model. Certainly a very simple model is easier to understand than a complex model, but a model with only a few equations or relationships can also appear complicated. Simple stochastic equations are not so simple to someone not trained in probability theory. Understanding depends on the education, training, and experience of the analyst using the model. Even when

the model is understood, the complex relationship of the outputs to the potentially large number of inputs and assumptions of a campaign model requires an analytic process (which is usually not part of the model) to identify the causes and effects in a study. This process is important for separating erroneous or misleading results from those that are truly plausible and justifiable.

The most important thing to understand is that transparency is not an inherent attribute of any model. Software features typically thought of to enhance the transparency of the model include

- summary or aggregated outputs
- map graphic outputs
- error-, limit-, and cross-checking of inputs
- graphical user interface
- automated sensitivity testing.

We do not mean to minimize in any way the great contribution these computing and data-processing capabilities can make to the understandability of the model. Too often, however, little or no attention is given to the analytic processes mentioned above. Even the physical model relating force to mass and acceleration ($F = ma$) is probably not understood by a large segment of the general population. Contrary to beliefs still held in the community, transparency is usually not obtained by increasing the detail or verisimilitude of the model. Increasing the apparent “realism” increases complexity and often adds more detail than is necessary for many applications of the model.

In the main report, we discuss more thoroughly how transparency can be achieved by

- **The analytic process.** The first step is to define the analytic approach to the problem in a way that helps to provide an understanding of objectives, measures, constraints, and alternatives, as well as of the explanatory logic for observations and recommendations.
- **Hierarchical sensitivity testing.** Classical sensitivity analysis examines how changes in inputs affect outputs. Typically, the

assumptions and input changes are too numerous to examine exhaustively. One common approach is to apply some kind of generalized experimental design or response-surface methodology. However, for campaign analysis, it is soon realized that these traditional approaches work only for simple problems and fail when the number of variables gets large. It is therefore more appropriate to adopt a hierarchical approach that relies on some knowledge of the problem, limiting the space of sensitivities that must be calculated.

- **Comparative analysis.** Here, the idea is to learn through understanding the differences in similar analyses. Although this process requires a good deal of effort (perhaps more than is affordable), comparisons of this kind have provided greater insight and transparency into the models and assumptions used. This is generally done with different models, although a variation could involve a different group using the same model and developing at least some of its own data and assumptions.
- **Education and training.** It should be obvious that an analyst who really understands a model will be better able to explain its results than someone just learning. What may not be obvious is that, for most campaign models, this understanding takes a long time, perhaps years, and it takes more than just introductory training with the model for military operations.

In the end, trust in the model, analyst, and data will provide some comfort that mistakes have been avoided, but it will not substitute for the explanatory transparency developed by the analytic process.

CONCLUSIONS: A PROGRAM FOR THE FUTURE

Future model-based campaign analysis depends on the resolution of a number of issues. We have emphasized the importance of focusing on analysis rather than model verisimilitude as the means of significantly advancing campaign analysis. It is necessary for the community to address some of the key data issues impeding campaign analysis, primarily by better cooperating in data production and sharing and by opening analyses up for greater community review. Certainly, the models should be improved in terms of more-flexible structures, variations in resolution, better representation of combat phenomena (particularly C⁴I), and greater transparency. This final section summarizes some of the actions that the defense modeling and analysis community should take to move campaign analysis into the next generation. These actions are explained in more detail in the last section of the main report:

1. Educate analysts and decisionmakers about the needs, methods, and limitations of model-based campaign analysis.
2. Balance the emphasis on models with an emphasis on improving analysis, particularly defining objectives and measures, building the rationale for conclusions, and better informing decision-makers.
3. Improve database development and sharing within the defense community.
4. Design and develop a set of campaign models with a range of capabilities.

5. Focus research and development on the effects and representation of key combat phenomena.
6. Adopt a more “scientific” approach to analysis, including critical peer review and broader disclosure of methods and results.

Ongoing DoD initiatives, particularly the Joint Analytic Modeling Improvement Program (JAMIP), are trying to address many of these issues. This and the main report provide specific suggestions that we believe are necessary for these efforts to achieve next-generation capability to support analysis.

In conjunction with this, the authors applaud the DoD’s current review of campaign modeling, and recommend that a heavier emphasis be placed on the approach and requirements for campaign-level *analysis*. A similar review of *analysis* could summarize the activities of current DoD analytic organizations and estimate the future needs for analysis, evaluate the approaches currently being used in analysis, evaluate the use of campaign models in analysis, consider the effects of new models and Advanced Distributed Simulation on analysis, and compare the projected needs for analytical staff. The review should be done by a committee composed of experts, users, and practitioners of analysis. It should be oriented not solely toward cost savings or efficiency but toward improving the analytic capabilities and products of the defense community. It should not focus solely on the models used for analysis. Rather, it should consider the questions being asked, the analytical approaches, the management of data, the resource constraints to analysis, the role of models in defense analysis, the products of the analysis, and the influence of those products on defense policy decisions.

REFERENCES

Bennett, Bruce, et al., *JICM 1.0 Summary*, Santa Monica, Calif.: RAND, MR-383-NA, 1994.

CACI Products Company, *MODSIM II The Language for Object-Oriented Programming: Reference Manual*, 1994.

Dewar, James A., Stephen C. Bankes, James S. Hodges, Thomas W. Lucas, Desmond K. Sanders-Newton, and Patrick Vye, *Credible Uses of the Distributed Interactive Simulation (DIS) Environment*, Santa Monica, Calif.: RAND, MR-607-A, 1996.

DIS Steering Committee, *The DIS Vision: A Map to the Future of Distributed Simulation*, Version 1, May 1994.

Hillestad, Richard, and Lou Moore, *The Theater-Level Campaign Model: A Research Prototype for a New Generation of Combat Analysis Models*, Santa Monica, Calif.: RAND, MR-388-AF, forthcoming.

Hodges, James S., and James A. Dewar, *Is It You or Your Model Talking? A Framework for Model Validation*, Santa Monica, Calif.: RAND, R-4114-AF/A/OSD, 1992.

Johnson, Irene M., "Anti-Armor Advanced Technology Demonstration (A2ATD), Experiments 2, 3, 4, and 5: Independent Evaluation Plan and Test Design Plan," AMSAA Combat Integration Division, Division Note No. DN-CI-1, May 1994.

M1A2 SIMNET-D Synthetic Environment Experiment Committee,
*Results of the M1A2 SIMNET-D Synthetic Environment Post-
Experiment Analysis*, May 1993.

U.S. Department of the Army, *Distributed Interactive Simulation
(DIS) Master Plan*, September 1994.